

Palaeoenvironments and correlations of the Carboniferous rocks in west Fermanagh, Ireland

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Geological map of west Fermanagh	<i>in rear pocket</i>

Synopsis

The Carboniferous (Dinantian and low Namurian) rocks of west Fermanagh, south of Lower Lough Erne, are correlated with strata from surrounding areas in north-western Ireland and divided into formations dated faunally and by the recognition of major sedimentary cycles. The proposed Ballyshannon Group consists of marine shales and limestones with two deltaic sandstone intercalations; the Dartry Group (new name) is entirely marine and includes a mud-mound 'reef' phase; the Leitrim Group is of mixed marine, intertidal, lagoonal and deltaic sediments and includes sabkha deposits which may be correlated with those of eastern Canada.

Introduction

Since 1952 the Carboniferous geology of several areas of north-west Ireland has been described, but west Fermanagh has remained largely neglected since the original map (sheet 44, 1884) of the Geological Survey of Ireland and the Memoir (Symes & Wilkinson 1886) were published. The region investigated lies between Lower Lough Erne and the borders of counties Leitrim and Cavan (Fig. 1). Our purpose is to describe those features of the Carboniferous succession in the area which allow these rocks to be interpreted in terms of palaeoenvironments and permit their correlation with adjacent areas and with the Major Cycles of sedimentation described by Ramsbottom (1973).

This paper results from work carried out by the authors independently from 1962 to 1974.

T. R. M. is generally responsible for the Leitrim Group and C. H. C. B. for the older strata. During this time we have described elements of the faunas: brachiopods by Brunton (1965, 1966a, b, 1968), fish by Gardiner & Mason (1974), while bryozoans have been studied by Tavenner-Smith (1965, 1973). A small syncline, preserving the youngest strata, has been described by Brandon (1972), and Wilson (1964) discussed some of the large Tertiary dykes in the area. Sheridan (1972) has presented a review of work on the Upper Old Red Sandstone and Lower Carboniferous rocks of north-west Ireland, in which he provided some useful information on a borehole sunk in west Fermanagh which penetrated to unexposed marine Tournaisian rocks.

Lower to middle Viséan strata mainly occupy areas of low ground below about 150 m and are not well exposed. The uplands to the south provide extensive dip and scarp exposures in the mid- to upper Viséan limestones and sandstones, although the interbedded and overlying shales, which extend into the Namurian, are commonly limited to stream-section exposures.

The exposures in west Fermanagh display the succession more completely than those of adjacent areas and four major cycles of transgression and regression from low Viséan (V1b) up to the low Namurian (E1) are recognized. Most of the formation names are derived from the areas of Sligo, described by Oswald (1955), or Leitrim studied by Brandon (1972), but we introduce new stratigraphical Group names.

After completion of this work the Geological Society of London published its report on 'A correlation of Dinantian rocks in the British Isles' (George *et al.* 1976). This proposed regional stage names corresponding to the six Major Cycles of Ramsbottom (1973), and we have added these names to Fig. 2. We have not emended our script since the stage names correspond to the cycles of sedimentation we discuss and because we disagree with the positioning of some of the cycle/stage boundaries suggested by George *et al.* for north-west Ireland. In general the cycles of sedimentation (Ramsbottom 1973) start with marine, commonly transgressive, sediments. The regional stages generally follow this concept, but in north-west Ireland George *et al.* (1976) place the start of some regional stages at the bases of sandstone sequences we believe to be of regressive, deltaic origin. Thus, there appears to be some inconsistency in the application of the stage boundaries and we feel it is inappropriate at present to define their positions stratigraphically in north-west Ireland; compare Fig. 2 with George *et al.* (1976: fig. 15).

Rock stratigraphical names

Groups

The generalized succession in west Fermanagh is illustrated in Fig. 2. The rock units from the Ballyshannon Limestone to the Dergvone Shale are here considered as formations. These are divided into three Groups: the Ballyshannon Group, from the base of Ballyshannon Limestone up to the top of the Mullaghmore Sandstone; the Dartry Group, which finishes at the base of the Meenymore Formation, and the Leitrim Group, a unit named by Brandon (1972) for the Meenymore to Dergvone Shale Formations but without a defined upper limit. (In his thesis of 1968 Brandon assigned strata from the Glenade Sandstone up to the younger Lackagh Sandstone to the Leitrim Group, and all units below this to what he called the Sligo Group, a name which hitherto remained unpublished.)

The Ballyshannon Group includes the oldest known Carboniferous rocks in north-west Ireland. These are commonly exposed as basal conglomerates of the Ballyshannon Limestone, at the base of the Bruckless Grits and Conglomerates in Co. Donegal, or as the Boyle Sandstone of the Carrick-on-Shannon area. The relatively abrupt change from the Mullaghmore Sandstone to the Benbulbin Shale marks the base of the Dartry Group. Although there is no indication of unconformity between the two, the rocks of the Dartry Group are more consistently marine limestones than those of the Ballyshannon Group. Brandon (1972) mentions the Dartry Limestone Group, but without definition, and since we include formations other than the Dartry Limestone we omit Limestone from the Group name. Brandon's unpublished thesis name 'Sligo Group' could be used as a super-group to unite the Ballyshannon and Dartry Groups.

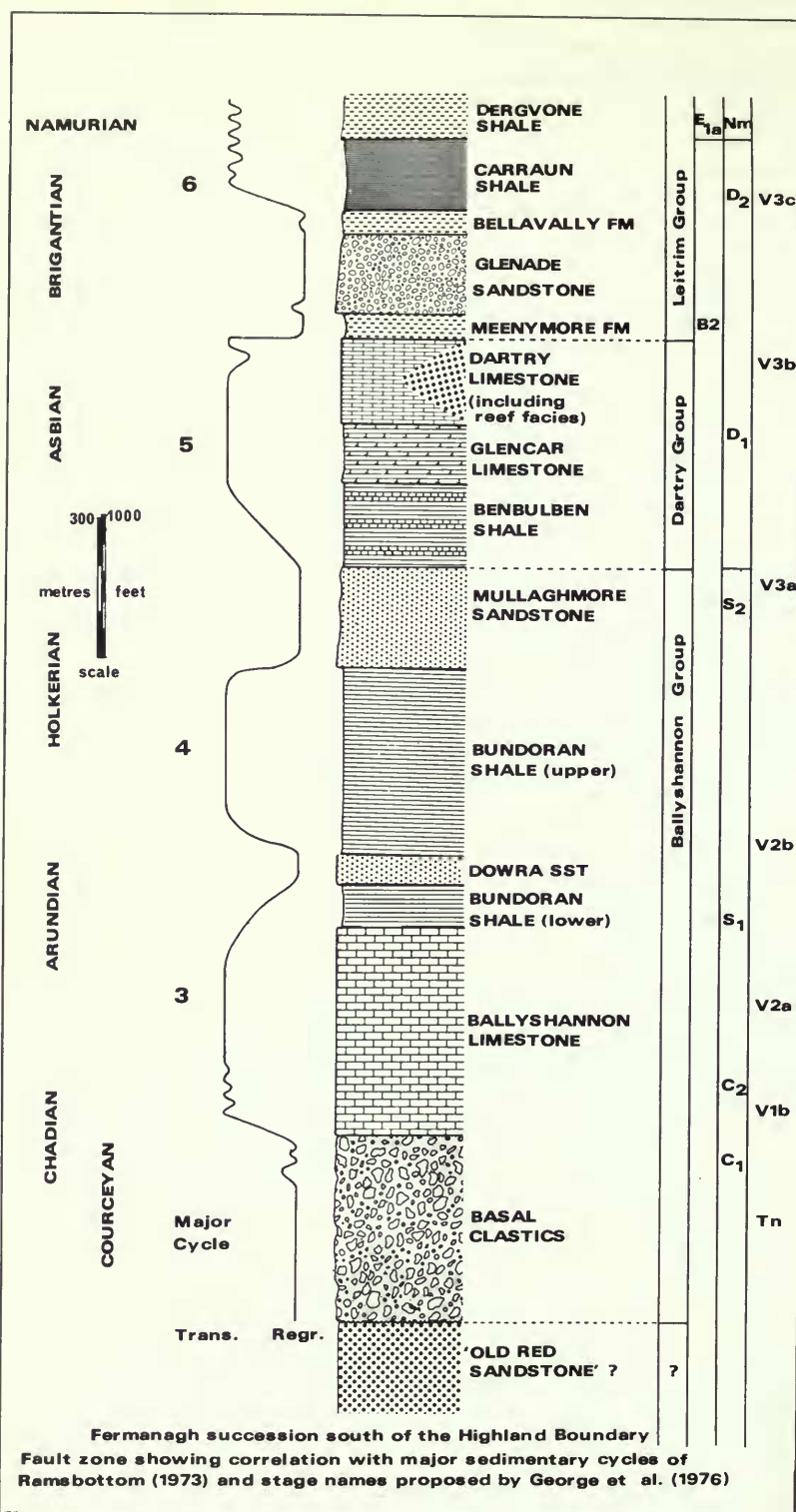


Fig. 2. The generalized geological succession in west Fermanagh south of the Highland Boundary Fault zone. The Basal Clastics and Dowra Sandstone are known in the area only from bore-hole evidence. In the north-west of the area the Ballyshannon Limestone rests directly on a Moianian basement, as shown in column F of Fig. 6, p. 104. Zonal correlations are indicated on the right.

The junction between the Dartry Limestone Formation and the Meenymore Formation varies from apparent conformity to erosional disconformity. This junction marks the base of the Leitrim Group but the youngest formations are not exposed in west Fermanagh.

Formations

The formation names follow the rock unit names proposed by Oswald (1955) up to the Dartry Limestone, and by Brandon (1972) from there upwards, with the following exceptions. Basal Clastics is used informally to denote the unexposed mixed basal Carboniferous rocks in west Fermanagh, known only from rather scant bore-hole information. Similarly, the Dowra Sandstone was named from Dowra no. 1 bore-hole, situated north-east of Lough Allen (Sheridan 1972). In this bore-hole the sandstone is 114 m thick from a depth of about 1270 m.

The type localities of the rock units described by Oswald (1955), and here accorded formation status, are as follows:

1. Ballyshannon Limestone – at Ballyshannon and the lower reaches of the river Erne, about 20 miles (32 km) north-west of Sligo.
2. Bundoran Shale – the foreshore and north side of Bundoran bay, about 16 miles (26 km) north-west of Sligo.
3. Mullaghmore Sandstone – the headland of Mullaghmore, 14 miles (about 23 km) north of Sligo.
4. Benbulbin Shale – exposures on the lower slopes of the mountain bearing this name (spelt Benbulbin on many maps), about 6 miles (10 km) north of Sligo.
5. Glencar Limestone – the north side of Glencar where the formation is well exposed on steep southern flanks of the Benbulbin range.
6. Dartry Limestone – this takes its name from the Dartry mountains, between the Benbulbin range and Lough Melvin to the north. The formation occurs in most of the highland areas of counties Sligo and Leitrim and is well exposed to the south of Glanade Lough, between the Benbulbin and Dartry ranges. The limestone is typically dark to light grey, often crinoidal, and chert-bearing in contrast to the lime mud mound facies (reefs of previous authors) developed within this formation.

The Meenymore Formation was described by Brandon (1972), who points out that it is equivalent to the oldest part of the Aghagranian Formation as described by West, Brandon & Smith (1968). In part, this formation is also equivalent to the Glenade Shales and Roscunnish Shales of Oswald (1955) and Caldwell (1959) respectively. The name is taken from Meenymore Townland, Glenboy, about 3 miles (5 km) ESE of Manor Hamilton, Co. Leitrim. The formation appears to be thin in this area and we suggest that the type locality, which has not yet been established, should be at the Aghagranian locality described by West, Brandon & Smith (1968) as the type locality of the Aghagranian Formation. The Aghagranian stream section lies about 1.5 miles (about 2.5 km) ENE of Drumshambo at the south end of Lough Allen, Co. Leitrim, where West, Brandon & Smith recorded 38.4 m of Meenymore laminated dolomite, limestones and shales.

The Glenade Sandstone was named by Oswald (1955) for the sandstones capping parts of the Dartry mountains north of Glenade. However, in this region no younger formations are known so its upper boundary cannot be established. Brandon (1972) used the term for equivalent sandstones in Co. Leitrim and estimated their thickness to be about 200 m in the Doagh Outlier region of west Fermanagh. We agree with this figure and believe our area provides a more complete sequence than exists in the Dartry hills. In Fermanagh the passage from the Meenymore to Glenade formations can be observed in sections of streams flowing north off the sandstone uplands, about 0.75 mile (1.2 km) south-west of Knockmore summit, 2.5 miles (4 km) WSW of Derrygonnelly village. The top of the Glenade Formation is difficult to demonstrate owing to poor exposures at the base of the Bellavally Formation. However, between the sandstone hill of Trustia (993 ft (303 m) high and 5 miles (8 km) slightly south of west of Derrygonnelly) and Doagh school (about 1 mile (1.7 km) to the north) there are stream exposures of Bellavally shales and Doobally sandstone. Our interpretation (Mason 1978) differs slightly from that of Brandon (1972), who did not recognize the shales and Doobally sandstones of the Bellavally Formation.

Stratigraphical succession

The Ballyshannon Group

Tournaisian. Rocks of proven Tournaisian age are not exposed in the area but are known from the deep bore-hole at Big Dog, about 9 km WSW of Derrygonnelly, from a depth of over 1500 m. This bore, drilled by Marathon Petroleum (Ireland) Ltd, penetrated between 500 and 600 m of sandstones, shales, thin limestones and anhydrites, thought on macro- and micropalaeontological evidence to be of Upper Tournaisian (Tn3c) age by Sheridan, Hubbard & Oldroyd (1967), before being abandoned while still in marine strata. This great thickness of mainly arenaceous Carboniferous sediment contrasts with the few metres of basal conglomerates and dolomites reported (Oswald 1955) only about 15 km to the north-west of Big Dog in the Ballyshannon region, at up to 50 m above sea-level. Here these basal Carboniferous rocks are of low Viséan age (Sheridan 1972). Thus over about 15 km there is a fall in the base of the Carboniferous of nearly 2000 m and a corresponding increase in its age. In addition, the underlying strata in the Ballyshannon region are metamorphosed Moinian schists, whilst to the south-east, although not proven in the Big Dog bore, folded Lower Devonian and Old Red Sandstone rocks underlie the Carboniferous. Sheridan (1972) discussed the possibility of this apparently steep palaeoslope being the result of pene-contemporaneous fault movement but concluded that block faulting of an early Viséan age resulted in the removal of the Tournaisian and Old Red Sandstones from the Ballyshannon horst region. It is becoming increasingly clear that some rocks in the British Isles much resembling the upper Old Red Sandstone (see Gayer *et al.* 1973) are really Tournaisian in age; these arenaceous transitional beds may be dated using spores, as has been done in Belgium. The lithologies of the lowest 600 m or so of the Big Dog bore indicate shallow marine and lagoonal conditions. Taken together, these two points lead to the conclusion that probably there was a long mid- and lower Tournaisian history of slow deposition in the area while the Old Red Sandstone lands gradually subsided. Periodically the lands were flooded with marine waters which led to the development of evaporites. Tournaisian subsidence to the south-east of the Highland Boundary Fault line was probably greater than that in the Ballyshannon region so that only thin, very condensed, erosional and regressive sediments older than V1b remain on this horst.

These, as yet poorly known, subsurface beds correlate with at least the upper part of Ramsbottom's (1973) First Major Cycle and may also include rocks within at least the lower part of his Cycle Two, which are of V1a age on the Belgian scale.

Viséan. Major Cycle Three, starting probably at the base of V1b (late C₂ of the coral-brachiopod zonation), spread northwards into north-west Ireland as an important transgression and resulted in the deposition of the Ballyshannon Limestone. The regressive phase is represented by the Lower Bundoran Shale and the sporadically-developed Dowra Sandstone.

The Ballyshannon Limestone strikes east-west from the type area into Co. Fermanagh, bordering the Moinian basement to the north, and in the region of Lower Lough Erne is repeated on the south shore by faulting. In our area this repeated section is exposed and extensively quarried from near Enniskillen in a north-westerly direction to Blaney. Being a relatively impervious and hard limestone it forms part of the south-west shore of the lake. Fine examples of *Delepinea destinezi* (Vaughan) have been described from the exposures on the north shore of the Lough (Pettigo Limestone of Simpson 1953) and date these rocks as from the C₂S₁ Zone.

The Dowra Sandstone was recorded from the Big Dog bore and, if correlated with the base of the Clonelly Sandstone of the Omagh basin (Simpson 1955), it represents a southerly extension of the conglomeratic and deltaic sandstones which spread from the north. Surface exposures of pre-upper Viséan (V3) sandstones are uncommon in west Fermanagh and the separation of those attributed to the Dowra Sandstone and those correlated with the Mullaghmore (Derrygonnelly or Macnean) Sandstone is difficult. Both may contribute to the topographical ridge extending from near Enniskillen to Derrygonnelly, where the undoubtedly younger of the two is exposed, marking the upper regressive phase of Cycle Four. At Derrygonnelly this sandstone is well-sorted and contains about 50% calcite cement; it is between 100 and 200 m thick. In addition to

the microfauna reported by Sheridan (1972) a transported macrofauna of bryozoans, brachiopods, coiled cephalopods and bivalves has been collected from temporary excavations which show the deposit to be fully marine. The environment in this area was probably a delta front, while coarser, less calcareous near-shore sands accumulated to the north. These sands, like the older Dowra Sandstone, were derived from the north and north-west, principally from the Moine and Dalradian areas of Co. Donegal. They extend from Donegal (the Mountcharles Sandstone), *via* the Mullaghmore type area on the Sligo coast, in a wide belt (known principally from bore-hole evidence) to the east, where they re-appear in the Dungannon region.

The shales below and above the Mullaghmore Sandstone, the Upper Bundoran and Benbulbin Shales respectively, are poorly exposed in west Fermanagh. They occupy low boggy ground, commonly covered by glacial drift and alluvium.

The Dartry Group

The shales and argillaceous limestones of the Benbulbin Shale Formation represent the return to open marine conditions at the start of Major Cycle Five (V3b). This is an important cycle in north-western Ireland, its rocks are varied and in west Fermanagh increasingly well exposed. No junction between the Mullaghmore Sandstone (Derrygonnelly Sandstone locally) and Benbulbin Shale can be seen in west Fermanagh and the shale is known only from small stream sections, principally in the Magho area, close to Lough Erne. It is a blue-grey muddy shale containing sparse thin limestones and bands of concretions, some of which contain a rich fauna of marine invertebrates.

The gradational passage from the Benbulbin Shale to the Glencar Limestone can be seen in the Magho area and from this point on a complete succession can be built up from a number of localities.

The Glencar Limestone succession in Fermanagh is very similar to that in Co. Sligo, consisting of approximately equal proportions of interbedded argillaceous limestones and shales, as described by Schwarzacher (1964) from the type area. These rocks are commonly very fossiliferous, especially in their upper sections, containing abundant brachiopods, bryozoans, crinoids and (more locally) corals, and it is from the highest beds of this Formation that finely silicified brachiopods and bryozoans have been described by Brunton (1966*a, b*, 1968) and Tavener-Smith (1965, 1973). Palaeocurrent study indicates that clastic sediment was probably all derived from the north and north-west, with open shallow seas extending to the south, whilst in the Sligo area the Ox Mountains appear to have contributed sediment along with that from the Donegal region (Schwarzacher 1968).

The full thickness of the Glencar Limestone is estimated at about 150 m, and towards the top the proportion of limestone to shale increases with thin beds of 'reefal' calcilutite or limestone conglomerates (Schwarzacher 1961) being found in areas where lime-mud mounds developed in the overlying Dartry Limestone.

The Glencar Limestone to Dartry Limestone junction varies in nature between those areas of regularly-bedded Dartry Limestone, such as the Magho region in the north-west of our area, and those localities in which lime-mud mounds developed at an early date, such as the Killydrum region. (Following Wilson's (1975) synthesis of carbonate facies the term 'lime-mud mound' is used here for those facies commonly in the past called 'reefs'. For the sake of brevity the term 'reef' is used on the Figures.) In the Magho area there is a gradational change over some metres of rock showing a reduction in the shale content and the development of relatively thick (5–20 cm) dark limestones containing nodular or tabular cherts. Unlike the Dartry Limestone of the type area, in Co. Sligo, thin shale partings persist almost throughout the formation in west Fermanagh. The junction in areas of lime-mud mounds is commonly abrupt, with the sole of the mud mound overlying crinoid-rich uppermost Glencar rocks. In other places the development of lime-mud mounds was delayed so that their bases are within the standard bedded Dartry Limestone facies. The overall picture during the time of deposition of the upper Glencar and Dartry limestones is of a reduction in the mud content and establishment of clearer-water shelf-margin

marine conditions. This period represents the most fully marine phase of Major Cycle Five, and the development of mud mounds indicates a shallowing of marine conditions, leading to the regressive phase and spread of deltaic Glenade Sandstone which terminated this major cycle.

In west Fermanagh there are strong lateral facies changes in the Dartry Limestone, from regularly-bedded chert-bearing limestones to lime-mud mounds (Fig. 3) which influence the present upland regions, commonly producing a knoll-like topography. Faulting between Magho and Killydrum, associated with the Highland Boundary Fault zone, partially obscures this facies change, but it also provides fine sections through some mud mound complexes.

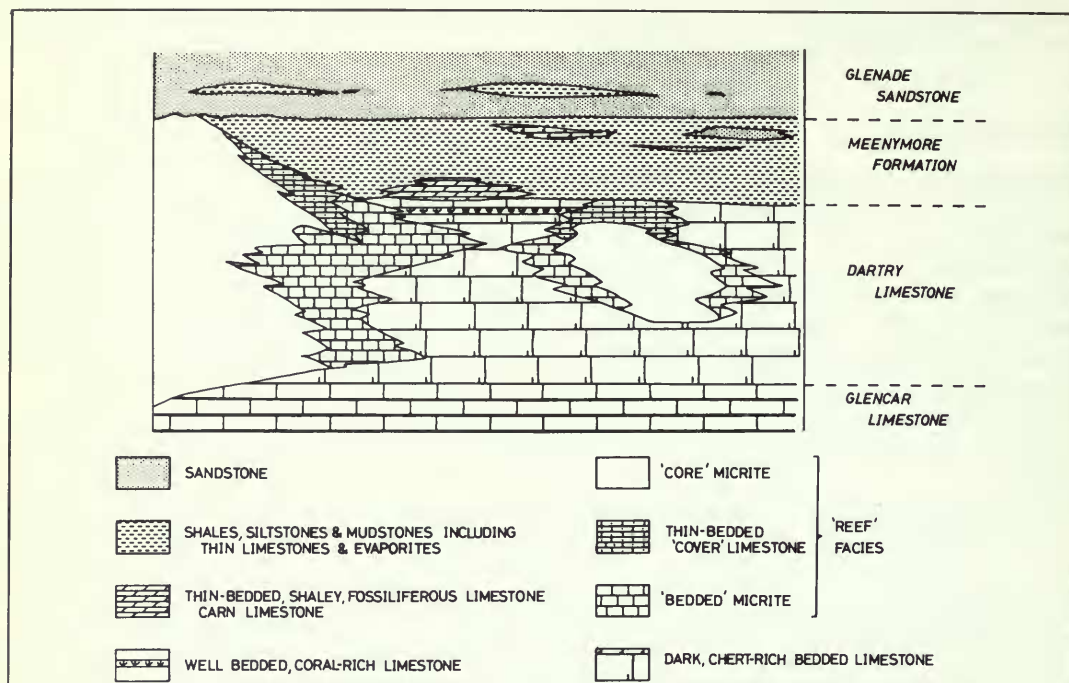


Fig. 3. Diagrammatic representation of the principal facies associated with lime-mud mounds occurring in the highlands of west Fermanagh. Lateral and vertical dimensions are not to scale.

The lime-mud mounds in this area are like those fully described by Schwarzacher (1961) from counties Sligo and Leitrim and resemble those from northern England (Black 1954, etc.) or, to some extent, the type Waulsort 'reefs' of Belgium, as well as the Waulsortian facies of south and central Ireland. Wilson (1975) widely discussed the various lithologies which have in the past been termed 'reefs', 'bioherms', etc. His general term for all such lithologies, 'carbonate buildup', was subdivided on compositional criteria to include his terms 'lime mud mounds' and 'linear mud accumulations', which were defined as lithologies in which 'lime mud matrix dominates other constituents such as organic boundstone and bioclastic debris. Such buildups are commonly perceived to accumulate both through hydrodynamic processes and *in situ* organic production.' It is this definition which most closely fits the facies previously termed 'reef complex' in the Dinantian of north-west Ireland. Within the nine facies belts recognized by Wilson (1975), belt five is mostly of organic reefs on platform margins, but includes non-organic reefs. Wilson distinguishes three types of facies. Type I is carbonate-mud and organic detritus accumulations; Type II is a margin slope, knoll reef, facies combining organic frame builders with lime-mud accumulations, and Type III is the facies of true frame-constructed organic reefs on platform rims. The Fermanagh carbonate buildup facies fall principally into Type I, but grade rarely into the Type II situation as the Dinantian sea became shallower.

The Fermanagh mud mound complexes include several lithologies, each of which may grade into the others laterally or vertically (Fig. 3). These include the following.

1. Massive core micrite in which bedding is absent, apart from occasional erosional planes. The rock is a light-coloured calcilutite containing a few cavities filled by sparry calcite. Fossils are rare.

2. Bedded micrite, which in hand specimen is virtually indistinguishable from the core micrite, contrasts in the field by being well bedded and commonly weathered to a rubbly surface. It forms the main mass of small complexes and grades from the tops and flanks of larger mud mounds having a true core, from which it dips at angles of up to about 40°. In these bedded micrites fossils are locally abundant, sometimes associated with the spar-filled cavities contributing to the rubbly weathered appearance. Elsewhere bryozoan fronds are preferentially aligned more or less parallel to the bedding planes (see Schwarzscher 1961).

3. Bedded cover limestones grade from the bedded micrite and, because the cavities are smaller and the individual beds thinner, their weathered surfaces erode to a fine rubbly appearance with individual pieces about 2 cm across. As the name suggests, these limestones are found above major mud mounds and are normally extremely rich (up to about 40%) in the debris of crinoids and blastoids. These organisms probably flourished in the shallow water at the tops of the mounds, locally in an environment more like the knoll reefs (Type II) of Wilson (1975). The limestone usually consists of broken shell debris producing a coarse lime sand.

The relationships of adjacent mud mounds one to another and to their surrounding chert-rich bedded limestone is one of lateral as well as upward sedimentation through time (Fig. 3). In this way adjacent mounds coalesced or overlapped and the height, or time, to which any one complex developed varied. Thus some mounds are overlain by several metres of normally-bedded Dartry Limestone with chert, though lacking shale partings, deposited before the first shale member of the Meenymore Formation. In other places, flanking the highest mounds, a few metres of well-bedded clean limestones, some of which contain widespread colonies of *Lithostrotion* corals, were deposited prior to the return of the chert-bearing limestone facies. These coral-rich limestones, near the top of the Dartry Limestone formation, indicate a short period of shallow-water clear marine conditions before the deposition of the very argillaceous, but fossiliferous, limestones and shales locally known as Carn Limestones. These represent the start of the strongly regressive phase towards the end of the Fifth Major Cycle and locally they are the basal rocks of the Meenymore Formation. Elsewhere in west Fermanagh mud mound cover limestones are followed directly by Meenymore shales or by even younger Glenade Sandstone.

The Leitrim Group

The Leitrim Group includes all the formations overlying the Dartry Limestone, up to and including the Namurian Dergvone Shale. Of these formations only the Glenade Sandstone is well exposed. The best outcrops of the Meenymore Formation are found near the town of Garrison, where streams have cut through the peat- and drift-covered slopes above Lough Melvin. The Formations younger than the Glenade Sandstone are restricted to the area around the Doagh Syncline, which has been described by Brandon (1972).

The lowest formation of the Leitrim Group is the Meenymore Formation, first described by Brandon (1972), with its type section in Co. Leitrim. This formation is found all over north-west Ireland (Brandon 1977) and its base is always sharply defined. It attains a maximum thickness of about 100 m in the Glen Syncline and is missing over some of the 'reef' areas of the underlying Dartry Limestone. The formation may be divided into lower and upper parts by the main marker horizon, the prominent calcareous Quarry Sandstone Member. The lower part of the formation is mainly composed of shaly limestones and mudstone, while the sequence above the Quarry Sandstone Member is characterized by the presence of laminated carbonates. In both the upper and lower parts evaporites are found.

As the Meenymore Formation is extremely variable in thickness and lithology, it is ideal for detailed sedimentological study, but this variation also makes it difficult to correlate the exposures.

A goniatite-nuculid fauna from Glennasheever contains *Bollandoceras* indicative of the B₂ subzone (V3b). This implies that the Glenade Sandstone above is of B₂ or P_{1a} age, since the Bellavally Formation contains a P_{1b} fauna.

The main lithologies of the Meenymore Formation may be summarized as follows.

- (a) Calcareous sandstones and siltstones.
- (b) Shaly and sandy limestones.
- (c) Laminated micrites, siltstones and dolomicrites (collectively known as laminated carbonates).
- (d) Limestones containing pseudomorphs after evaporite minerals.
- (e) Shales, mudstones and siltstones. Fissile, pyritic, micaceous and varying in colour.

The most characteristic lithologies are the laminated carbonates, and their presence suggests that the formation was deposited in a sabkha-like environment (Gardiner & Mason 1974), a conclusion which was supported by the discovery of evaporites.

The laminated carbonates can be subdivided into three main types.

- (a) Planar laminated carbonates; dolomite content variable, usually unfossiliferous.
- (b) Brecciated laminated carbonates; dedolomitized or with high dolomite content. Occasional fossil fragments.
- (c) Laminated carbonates; dolomitic, containing trace fossils.

These rocks were deposited in a peritidal environment, as they all exhibit algal fabrics.

The planar laminated carbonates consist of thin (5–15 cm) bands of flaggy carbonate, with a conspicuous lamination on the weathered surface. These laminae, which are parallel to bedding, are composed of very thin (0.1–1.0 mm thick), alternating layers of dolomite and calcite. It is likely that they were formed as described by Gebelein & Hoffman (1973), who claimed that there is sufficient magnesium complexed into organic algal sheath material to form dolomite during diagenesis. Scanning electron micrographs of the laminated rock types show the dolomite to be undoubtedly of secondary origin. Finely laminated lithologies like these are common in the geological column (Sander 1936; Sarin 1962; Laporte 1967; Hoffman 1970).

The brecciated laminated carbonates were formed by subaerial desiccation of algal mats under arid conditions. The broken fragments are polygonal, averaging about 1 cm² in area. The polygonal pieces are of a lighter buff colour than the greyish sediment-filled cracks separating them. Sections polished at right angles to bedding show the fragments of algal material to vary in thickness from 0.5 mm to 5.0 mm, whilst the sediment layers are 1.0 mm or less in thickness. In thin section these rocks show the following features.

- (a) Pseudomorphs of calcite after dolomite.
- (b) Palimpsest textures, with rhombic zones of ferric oxides remaining as ghosts within a new generation of calcite.
- (c) Possible dolomite inclusions within the calcite pseudomorphs (seen with the scanning electron microscope only).

These features fulfil criteria established by Shearman *et al.* (1961) to define dedolomitized lithologies. The mechanism offered to explain this phenomenon utilizes the reversible reaction



thus requiring a gypsiferous solution to effect dedolomitization. This could easily have been derived from the various evaporites within the Meenymore sequence, and the soluble magnesium sulphate produced by the reaction would be removed by rainfall. Gypsum was found at Killybeg crystallized along bedding planes and joint surfaces as a Recent deposit. Dedolomitization is essentially a near-surface or surface reaction.

The remaining laminated carbonate contains tube-like trace fossils, which are often concentrated on bedding surfaces. A detailed study of these (Mason in press) has led to the conclusion that they were the fossil remains of polychaete worm tubes. They were probably made by a small sedentary polychaete resembling the Recent species *Sabella microphthalma* which Neumann *et al.* (1970) describe as a common faunal element of subtidal algal mats of the Bahamas. These tubes exhibit a preferred orientation, and it is possible that they were sufficiently rigid to withstand

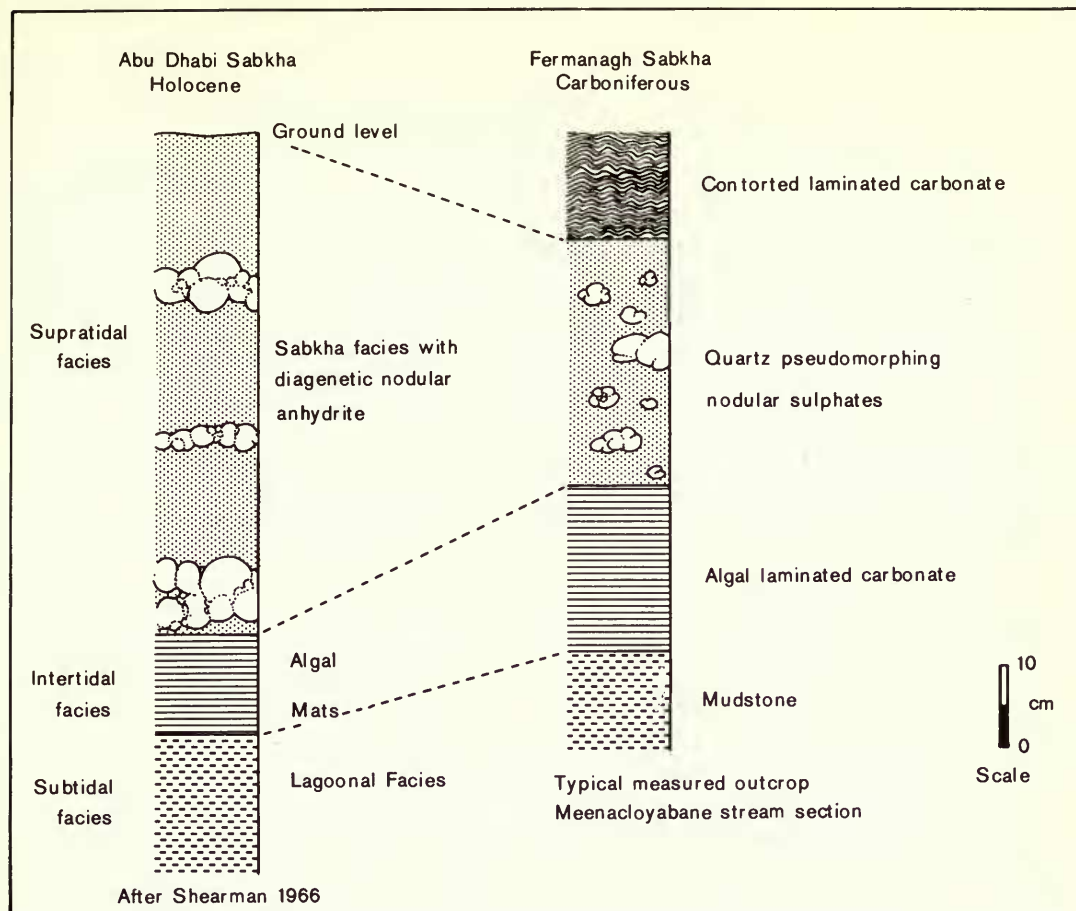
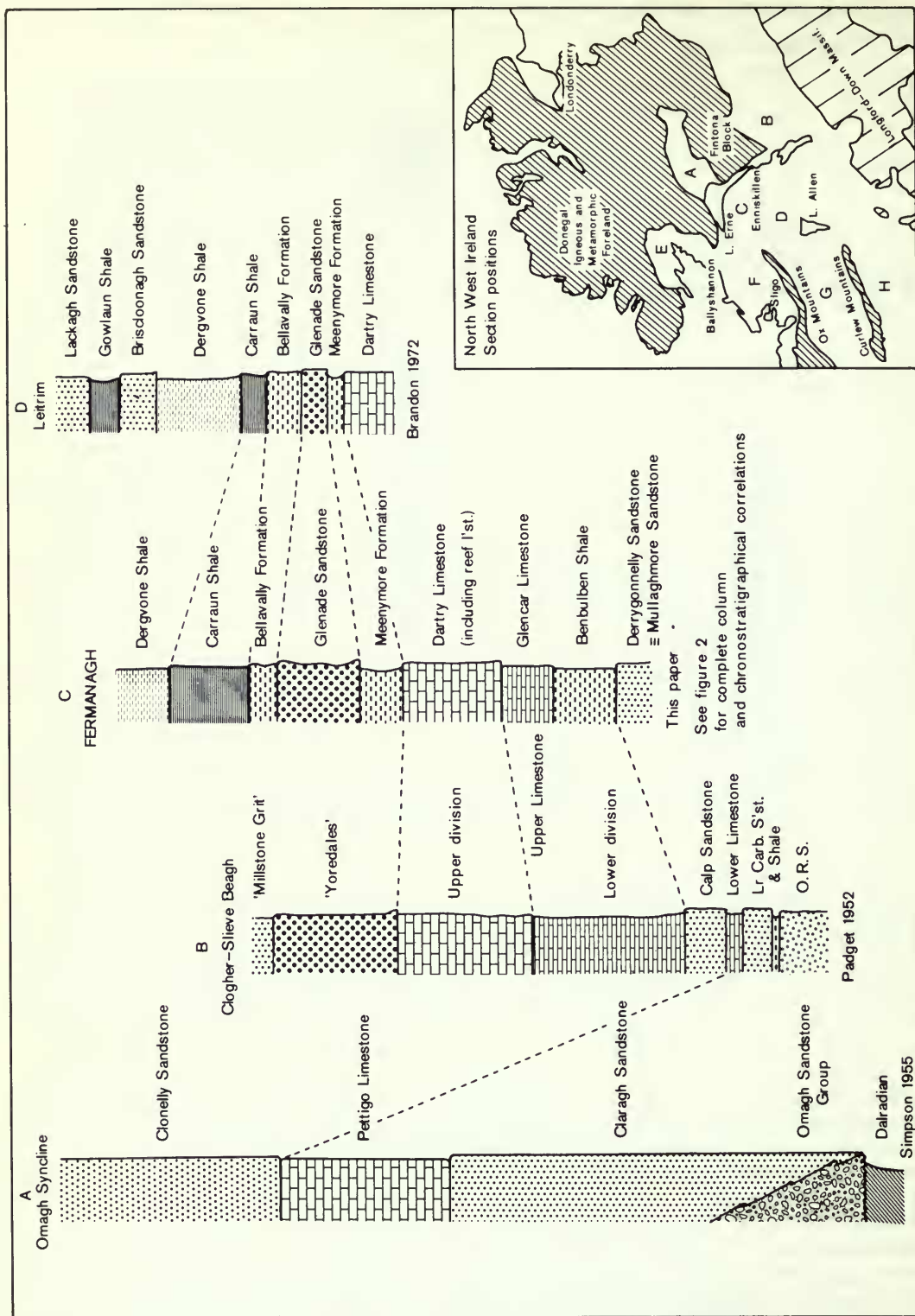


Fig. 4. A typical sabkha cycle from Abu Dhabi and the Carboniferous analogue from a section in Co. Fermanagh.

transportation and reworking by currents. The diagenetic history of this rock is one of progressive dolomitization.

Many of the laminated carbonates are contorted and folded, suggesting that they were still plastic when deformed. Examination of the different types of distortion suggested kinship with some of the algal zones described by Kendall & Skipwith (1968) from the Persian Gulf. One algal limestone from Shroneallappa contains rounded colonies of *Ortonella furcata* which closely resemble the algal colonies of the cinder zone (Kendall & Skipwith 1968).

If it is to be accepted that there is a close comparison between the west Fermanagh Meenymore Formation and the sedimentary regime of the present Persian Gulf, supporting evidence is required. In the Persian Gulf Shearman (1966) recognized a sabkha cycle of deposition comprising firstly sandy carbonate with sulphate nodules, then algal mats, and finally lagoonal facies. Similar cycles occur in the Meenymore Formation (Fig. 4), except that those of the Viséan have been altered during diagenesis. A diagenetic history may be constructed to show the sequence of replacement. The main difference between the Carboniferous and Recent sediments is the Carboniferous lack of calcium sulphate, most of which has been replaced diagenetically by celestite, chalcedonic silica (lutecite) and megaquartz. Lens-shaped pseudomorphs after gypsum, and megaquartz replacement of anhydrite nodules, are also recorded. It appears that the depositional environment during Meenymore times resembled the coastal sabkhas of the Persian Gulf at the present time.



The Glenade Sandstone is exposed as a series of prominent escarpments forming much of the high ground in the area. Sandstones are interbedded with thin shales whose presence may be inferred by the occurrence of shaly clasts in the basal parts of the sandstone outcrops. Some shales seen in a quarry face were pinched into lenses by compaction. Conglomeratic horizons are common near the base of the formation. They contain small (2 cm) shale clasts, well-rounded quartz pebbles (2–3 cm diameter) and coaly debris, thought to have formed *in situ* from drifted plant remains. Some horizons contain numerous unidentifiable plant fragments.

Petrographically the Glenade Sandstone contains *c.* 95% quartz, 4% calcite or dolomite cement and 1% feldspar. The occurrence of two generations of calcite, one of which is limpid and the other darker containing ferric oxide, suggests that an original dolomite cement has been dedolomitized. Rhombic crystals of iron-rich calcite resembling the rhombic ghosts of dolomite crystals occur in the brecciated laminated carbonates. In the type area Oswald (1955) described the Glenade Sandstone as containing up to 50% feldspar. The lower amount of feldspar in the Fermanagh outcrops probably reflects their greater distances from the inferred source areas to the north and north-west.

All the Carboniferous sandstones in Fermanagh thin southwards, and each sandstone in the succession advanced further south than its predecessor. The thickest sandstones in the Leitrim area are of Namurian age (E₂), suggesting that the shoreline was prograding and advanced south with time. The Glenade Sandstone thins from about 200 m in Fermanagh to about 30 m in Leitrim.

Compaction in the Glenade Sandstone, in addition to pinching out the shaly horizons, also produces a characteristic 'wavy' bedding, with 'waves' up to an amplitude of 0.75 m and wavelength 4 m. Most other sedimentary structures are localized. Current bedding readings suggest a northerly source for the sediment.

Large limestone clasts (500 ml) found in the basal part of the formation are thought to be eroded blocks of Dartry Limestone, as the basal Glenade Sandstone rests on mud mound limestone where the Meenymore Formation is attenuated or absent. These contacts are poorly exposed and can be deduced most easily from aerial photographs.

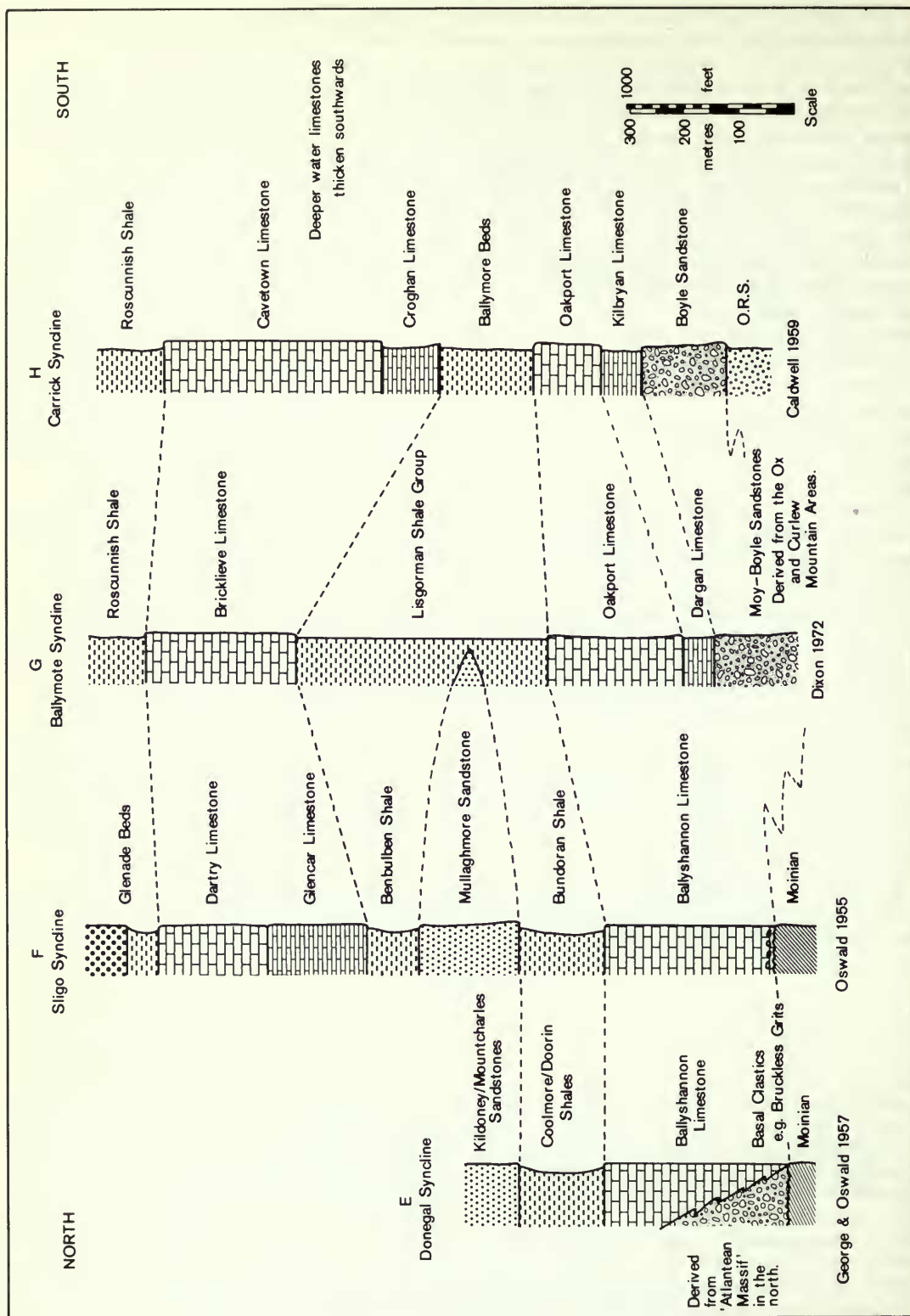
The formations above the Glenade Sandstone are poorly exposed in Fermanagh and crop out only in the Doagh Syncline. This is the most northerly occurrence in Ireland of these strata, the nearest related succession being found in Leitrim. It is only possible to construct the succession up to the Dergvone Shale by mapping the various limestone marker horizons, and by collecting their distinctive faunas (Fig. 2). In west Fermanagh the succession is about twice as thick as that in Leitrim, which reflects the close proximity of Fermanagh to the source of the sediment on the old Carboniferous continent.

Brandon (personal communication) has remarked on the apparent cyclicity of the Carraun Shale (Fig. 2), which is primarily composed of limestone–shale alternations, thus reinforcing Ramsbottom's (1973) views on the minor cyclicity of Major Cycle Six.

Correlations

Age determination and correlation based upon faunas in west Fermanagh is poor, except for

Fig. 5. Generalized stratigraphical sections A–D, based on published work and our own studies, showing major facies changes and their correlations with the formation names derived from Oswald (1955) and Brandon (1972). From left to right the columns represent increasingly southerly positions and are interpreted as being successively further from the Carboniferous landmass to the north. The Clogher–Sliève Beagh section (Paget 1952) may be atypical of that basin as a whole. Sheridan (1972) presented data from the Glenoo no. 1 well, drilled a few km south-west of Sliève Beagh, which when tabulated provides approximately 2260 m of sediment from near the base of the Dartry Limestone equivalent down to the top of the supposed Old Red Sandstone. This Glenoo succession includes about 250 m of sandstone, which can be correlated with the Mullaghmore Sandstone, and about 1900 m of limestones and thin shales of the Ballyshannon Limestone type. Below this about 1350 m of mixed sandstones, shales, occasional limestones and anhydrites were penetrated which appear similar to those recorded from the base of the Big Dog well in Fermanagh, where they are marked as Basal Clastics in Fig. 2, p. 94.



some of the younger strata. However, some faunas of significance have allowed us to correlate the formations in north-west Ireland (Figs 5, 6) and to suggest the zonal correlations we present in Fig. 2, p. 94. No stratigraphically important faunas have been described from the Ballyshannon Group, although where better exposed in County Sligo Oswald (1955) records *Michelina megastoma* (Phillips) (= *M. grandis*) and *Delepinea destinezi* (Vaughan) in the Ballyshannon Limestone itself. These are typical C₂S₁ or Cycle Three fossils. *D. destinezi* is also known from the equivalent limestone exposures on the north shore of Lower Lough Erne near Kesh (Simpson 1953). In this region Simpson (1955) reported *Davidsonina carbonaria* (M'Coy) from sandstone (? Mullaghmore Sandstone) above the local Ballyshannon Limestone and this would correlate with the S₂ or Cycle Four; however, this record has not been verified.

Only in the uppermost Benbulbin Shale are exposures good and fossils plentiful. Unfortunately, diagnostic macrofossils remain poorly known despite the excellence of silicified bryozoans and brachiopods described from the Glencar/Dartry Limestone junction. These faunas have been assigned by Tavener-Smith and Brunton to the D₁ Zone, or Cycle Five. The characteristic brachiopods of this Cycle, *Davidsonina septosa* (Phillips) and *Daviesiella llangollensis* (Davidson), found in central and northern England, appear to be missing from north-west Ireland. This absence may result from palaeoenvironmental differences between the pale bioclastic limestones low in the D₁ Zone, where they are normally found, and the contemporaneous muddy limestones of north-west Ireland.

Of the abundant silicified brachiopod species collected from Co. Fermanagh, *Plicatifera plicatilis* (J. de C. Sowerby), *Overtonia fimbriata* (J. de C. Sowerby), *Krotovia spinulosa* (J. Sowerby), *Productina margaritacea* (Phillips) and eomarginiferids such as *Eomarginifera trispina* Brunton are normally typical of D₁ limestones in Britain. Unfortunately, foraminifera are rare in most of these limestones and have not yet been studied in detail. However, small samples of Glencar and Dartry Limestones kindly examined by Professor R. Conil suggest to him (*in lit.* February 1975) a high V2b to V3a age for a low Glencar Limestone sample. A V3a age for this sample is equivalent to S₂ Zone and would thus extend Cycle Four of Ramsbottom (1973) to the base of the Glencar Limestone. From the overlying Leitrim Group shales, good P age goniatites (including *Goniatites striatus* (J. Sowerby) and *G. falcatus* Roemer from the Bellavally Formation) have been collected, so the exact age of the Dartry Group remains somewhat equivocal, but it must broadly coincide with the whole of the D₁ Zone or Cycle Five.

The base of the Namurian is marked by the occurrence of *Cravenoceras* cf. *leion* Bisat and *Eumorphoceras* sp. in the Dergvone Shale from the Doagh outlier. In addition, Brandon (1972) records *Eumorphoceras* cf. *rota* Horn and *E. cf. medusa* Yates from these shales, which are the youngest Carboniferous rocks in west Fermanagh.

Discussion

The depositional environments of the west Fermanagh Lower Carboniferous strata may be reconstructed by studying the fauna and lithologies. The sedimentary regime varied from shelf carbonates and shales to deltaic sandstones and coastal sabkhas, and the recognition of Major Cycles Three to Six demonstrates the value of this approach to broad stratigraphic correlation. If this cyclicity is to be of more general help in correlation it is necessary to consider the gross aspects of various Carboniferous successions in the northern hemisphere.

Fig. 6. Generalized stratigraphical sections E–H from areas as indicated in Fig. 5, based on published work, showing major facies changes and their correlations with the formation names derived from Oswald (1955) and Brandon (1972). From left to right the columns represent increasingly southerly positions and are interpreted as being successively further from the Carboniferous landmass to the north, and follow on from A to D (Fig. 5). In the Donegal syncline (George & Oswald 1957) there is considerable facies variation; in the northern parts of the area great thicknesses (over 800 m) of grits and conglomerates were recorded. This correlates with the thick pre-Clonelly Sandstone sequence of the Omagh syncline (Simpson 1955) shown in Fig. 5, A. The Highland Boundary Fault zone passes between sections F and G, affecting the pre-Carboniferous basement rocks as it does in west Fermanagh.

The map prepared by Smith *et al.* (1973) shows that the areas in which Lower Carboniferous sediments were laid down are now fragmented by continental drift, with some pieces now separated by the North Atlantic Ocean. As eastern Canada and Ireland were formerly much closer, one would expect to find evidence of Viséan evaporites and supratidal deposits in the Canadian succession. Schenk (1967), working on the Windsor Group of the Canadian Maritime Provinces, described lithologies which were 'almost identical' to the strand-line carbonates of the present Persian Gulf, Bahamas, Florida Bay and South Australia. He described two peritidal lithosomes, together forming the Macumber Formation, thought to be of Viséan age, and this formation may be closely related to the Irish Meenymore Formation.

Concerning the sequence underlying the Fermanagh Viséan succession, Belt *et al.* (1967) correlated the 'cementstone' facies of eastern Canada, Northern Ireland (Cultra) and the midland valley of Scotland. Recent work on the Irish fauna suggests that the 'cementstones' are of Middle Tournaisian age (Brandon, personal communication). Samples from this succession contain calcitized and dolomitized enterolithic structures similar to those described as calcitized anhydrite by Shearman & Fuller (1969) from the Devonian of Canada. It seems that during the Tournaisian there was an evaporitic interlude, and the successions in eastern Canada, Ireland and Scotland are again remarkably similar. Carboniferous evaporites are also known from the Middle Carboniferous of Svalbard (Spitzbergen) (Holliday 1966), the Permo-Carboniferous of Bjørnøya, Svalbard (Folk & Siedlecka 1974) and the Lower Carboniferous of Alaska (Armstrong 1970); it is likely that other occurrences remain to be discovered and described in Russia and North America.

Green (1961) concluded that the distribution of evaporites was limited to those areas falling between latitudes 45° N and 45° S. The British Isles, and probably Svalbard, would have been within these latitudes during Lower Carboniferous times (Smith *et al.* 1973), it is suggested that there is sufficient similarity between the British and Irish successions, and that of eastern Canada and possibly Svalbard, to permit them to be correlated on the basis of the over-all sequence.

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